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Efforts at Improving Modeling & Understanding of Plasma Conditions and Capsule Drive in Ignition Scale Hohlraums*

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Efforts at improving modeling and understanding of plasma conditions and capsule drive in ignition scale hohlraums*

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Current modeling of ignition scale hohlraums, including non-LTE detailed atomic modeling, and non-local electron transport, when compared to data, have results that bifurcate: Experiments with long-pulse (> 10 ns), gas filled hohlraums deliver less drive to the capsule than predictions; In contrast, implosions in short pulse (< 10 ns), nearly vacuum hohlraums behave as predicted. We present here our current activities in exploring various hypotheses for this difference, and plans to test them by using intermediate length pulse and intermediate density gas fill platforms.

After the first round of hohlraum experiments at the National Ignition Facility (NIF) in 2009, the ignition program adopted a new computational model, the so called High Flux Model (HFM) [1]. It uses a better non-LTE model than before, involving detailed configuration accounting (DCA) [2] and a better electron transport model than before, a non-local model [3], which, for simplicity, is often substituted by a "liberal" flux limiter, f=0.15. This model had success in explaining x-ray emission levels from Au spheres [1,4] illuminated at the Omega facility at the URLLE, though it did somewhat over-predict the emission levels for the greater than 1.8 keV emission. That model applied to NIF 2009 empty hohlraums did very well in predicting the x-ray emission emerging from the laser entrance holes (LEHs) [5]. In addition, as realized in 2010, the analysis, at that time, of the late 2009 full scale, 1 MJ gas filled ignition hohlraums, supported the use of the HFM to explain observations such as the Stimulated Raman Scattering (SRS) spectrum [6] and the observed behavior of the shape of the self emission of the hot spot [7]. Common to both of those, was a cooler plasma temperature than expected based on the previous standard model (a simpler average-atom ("XSN") non-LTE model, and a fixed, restrictive electron flux limiter of 0.05). This cooler temperature, due to more radiative and electron flux leaving the plasma, helped explain the SRS spectral shifts, as well as the symmetry behavior, making it more difficult for the inner beams of the NIF to propagate to the mid plane of the hohlraum, as they originally were designed to do.

Despite those successes, it was clear, even back then, that the time of peak x-ray emission (in jargon: "bang time") was later than predicted. This might have been due to capsule ablator issues, but the "view factor" experiment [8] determined that hohlraum drive predictions were the key issue. Given this over-prediction of drive, the ignition program has adopted a use of "multipliers", for convenience, on the laser itself, to better model the actual drive on the capsule [9]. This situation persisted for a number of years. In 2013 a simpler target (an indirect drive exploding pusher (IDEP)) was shot with a ~ 4 ns pulse (2 ns foot, 2 ns main power, which is much shorter than the ~ 20 ns ignition pulse), in a near vacuum hohlraum. It actually behaved in accord with the HFM without said "multipliers" [10], both in terms of observed x-ray emission from the hohlraum, (though, like the Au sphere, the prediction for x-ray emission at frequencies greater than 1.8 keV was high), and in terms of bang time .

Thus, a major mystery we are currently dealing with, is this bifurcation. Short pulse, near vacuum hohlraums, deliver drive to the capsule as predicted. Long pulse, full gas fill hohlraums deliver less drive to the capsule than predicted. In the reminder of this paper we describe plans to address this issue.

Clearly, one approach is to depart from one end of this pulse length/fill density spectrum and march towards the other end. As an example we consider short pulse empty hohlraums (or perhaps one with a simple exploding pusher target in order to monitor bang times) as we raise the fill density 10x from near vacuum, but still 5x below the ignition gas fill value. In Figure 1) we show the pulse shape and the predicted differences in observed x-ray emission depending on what hohlraum model is used.

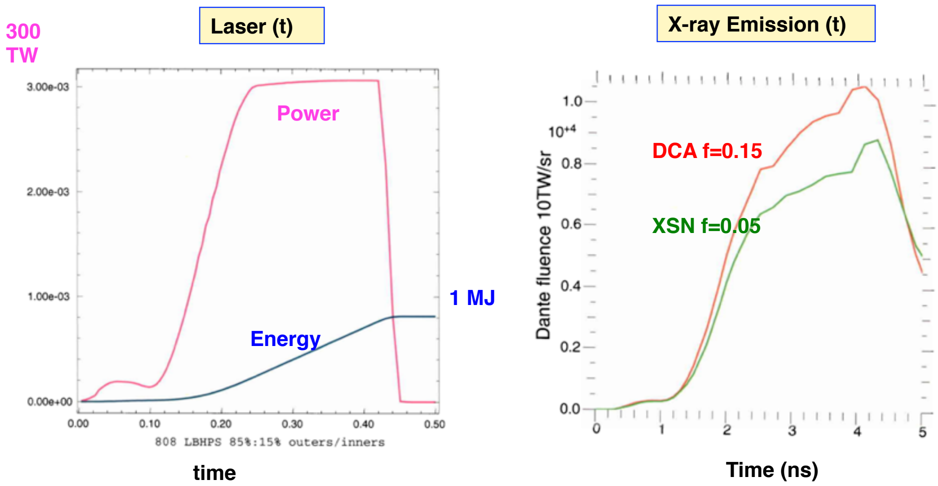

Figure 1: Laser pulse power and energy vs time. Predicted total x-ray emission vs time for the old "standard model" and the HFM.

The lesson of Figure 1 is that there is a large difference in the total x-ray emission predictions of the two models. For the Omega Au spheres the difference was 100%; for 2009 NIF empty hohlraums, 35%; but for the full ignition hohlraums only about 15%. Thus the proposed intermediate gas fill experiments have a sizable, easy to see, difference of about 25%.

In Figure 2 (next page) we show the different plasma conditions (Te in particular) for those two models. If hohlraum plasma characterization techniques mature, such as dot spectroscopy, then Figure 2 shows that there is a large enough difference in predictions of Te to hopefully be measured.

Another approach to studying our basic issue is to start with an open geometry, namely the Au sphere on Omega, and extend it towards a gas filled hohlraum condition. We envision doing so by surrounding the Au sphere with either a gas filled "gas bag", or with a low Z foam. In either case we model this more complicated system (but still in an open geometry) and predict that indeed the gas or foam surrounding the Au sphere can modify its density profile as it heats and expands, (compared to a bare sphere) and can be more like the "gold bubble" that expands off the wall of a gas filled hohlraum. The Omega system offers the opportunity to use Thomson Scattering to measure the plasma conditions of that experiment, including Te, Ti, and Z, as a function of time at a given position, and then vary the position in subsequent shots.

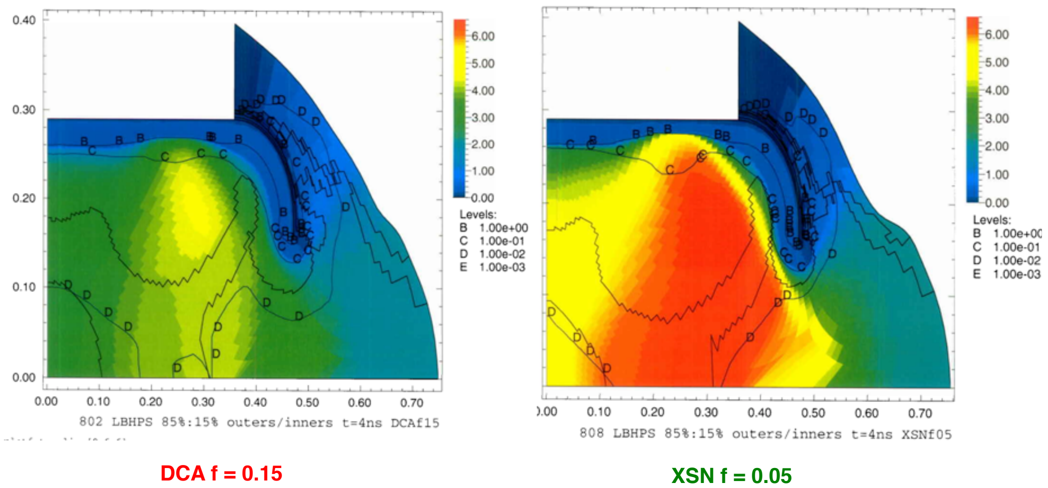

Figure 2: Differences in predicted electron temperature vs. model

Besides these integrated experimental approaches, we are considering a variety of theoretical hypotheses for explaining our basic issue. Along with those theories, could come dedicated, focused experiments to test these hypotheses.

The first such idea is the notion that the standard hohlraum expands outward in time. This is driven by shocks launched by the subsonic Marshak wave progressing deeper into the wall from the hot inside towards the cold outside. For long pulse irradiations, the wall moves about 7x its in-flight thickness. Thus it is possible that the hohlraum wall breaks up. For a short pulse drive, however, this does not happen on the time scale of the pulse. An obvious experiment to try is to use a very thick walled hohlraum for a long pulse drive and see if it improves the capsule drive performance.

Another hypothesis involves the mix of the Au wall blowoff with the hohlraum fill gas. This could reduce drive and change symmetry. A time dependent SXI x-ray diagnostic might image the mix. Currently that instrument is time integrated. Absent that, pulses that are truncated in time can provide the time dependence.

An additional hypotheses invokes laser plasma instabilities (LPI) such as SRS that occurs internal to the hohlraum, whose signals do not emerge out of the LEH and are thus "invisible" to us. This internal LPI can redistribute laser energy into places that convert their energy to x-rays less efficiently, and thus lower drive. Supportive of this hypothesis (though by no means definitive) is the observation that the near vacuum short pulse hohlraums, whose drive is well modeled by the HFM, exhibit very little LPI.

Along an entirely different "axis", are numerical issues. Efforts at doing the radiation hydrodynamics in a more numerically convergent way are underway[11]. Efforts at improving the DCA model are also ongoing. In particular, we are exploring better ways for the model to automatically, and in a physically well based way, transition from its LTE treatments to its non-LTE treatment.

Finally we mention another approach to this basic issue. While it seems clear that the high electron flux is an important element of the HFM, especially for the Au spheres, it may not necessarily translate to a long pulse gas filled geometry. The Au sphere has a very uniform plasma environment. Many beams overlap, and its self generated x-ray emission bath also smooths out non-uniformities. Empty, and near empty hohraums, with short pulses, still have the NIF beams relatively fully bathing the hohlraum walls. In contrast, the long pulse gas filled hohlraum has beams that tend to separate. Separated beams have radial gradients that can lead to B fields and flux inhibition. Anecdotally, on the Omega laser, experiments to characterize empty hohlraum conditions via Thomson Scattering were first compromised by non uniformities using conventional, tight beam illumination geometry. When the beams were spread and repointed to more uniformly bathe the hohlraum walls, the analysis had to use a relatively high flux limit of about 0.1 to successfully model the observations [12]. A restrictive flux limit for the long pulse high fill gas hohlraums can reduce the drive. It will make the hohlraum plasma temperature somewhat higher, though with retaining the DCA non LlTE mode, radiative losses will keep that difference from the HFM rather moderate (~ 1/2 keV hotter for the DCA + restrictive flux limit). Perhaps that is not so high so as to compromise the agreement with the SRS spectrum. The higher Te will change the symmetry predictions. However, there are many ingredients to the modeling that needs to be included to more fully predict the symmetry, including the effect of the tent that holds the capsule, self consistent SRS propagating backwards through the hohlraum, local or non local deposition of its related electron plasma wave or the hot electrons it produces, the aforementioned mix of the Au wall with the fill gas etc.

In summary there is a rich host of experimental and theoretical approaches for studying the apparent paradox as to why the HFM works well in predicting drive for near vacuum short pulse hohlraums, but over-predicts drive for long pulse gas filled ignition scale hohlraums. Characterizing the plasma conditions is an important element to solving this mystery.

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